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Control of Bacterial Wilt (Bacterium solanacearum) of Tobacco as Influenced by Crop Rotation and Chemical Treatment of the Soil

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SUMMARY

Bacterial wilt, one of the most destructive diseases of tobacco, not only reduces the production of a crop in great demand by the armed services as well as by civilians but also results in a waste of time and labor when both are urgently needed by the farmers who grow tobacco along with other crops. Wilt-control experiments carried on since 1935 have brought about the completion of preliminary work with wilt-resistant strains of tobacco and with urea treatment of the soil, the most promising control measures now in sight, but these new methods have not been made available for commercial use.

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Control experiments, however, have included studies of crop rotation, the method now in use, and these studies have provided information of immediate value to the tobacco producers who must continue to depend on crop rotation for wilt control during the next few years. The crop-rotation findings are thus emphasized in this circular, the contents of which may be further summarized as follows:

Bacterial wilt was not eliminated from the soil by 1 to 4 years of bare fallow, but considerable variation in the degree of control was obtained by rotations with different immune crops. Thorough elimination of weeds susceptible to wilt did not increase the effectiveness of rotation. The results showed that control by crop rotation does not depend entirely on the wilt resistance of the plants grown.

Soybeans, previously considered susceptible to wilt, can be used safely in rotation on wilt-infested land, a discovery particularly important when soybean culture is being rapidly expanded. Under exceptionally severe wilt conditions in 1939, rotations of corn, soybeans, and redtop proved more effective than rotations of sweetpotato, crabgrass, or native weeds.

In the 1939 season a rotation period of 3 years between tobacco crops was more effective than 1 to 2 years. Rotation periods of 1 or 2 years, however, gave satisfactory control in seasons when the disease was less severe.

The use of wilt-resistant tobacco strains in combination with crop rotation showed that increased wilt control is obtained by growing slightly resistant strains on land rotated to corn for 1 year, but little increase in control was obtained where strains that were moderately or highly resistant were grown on rotated land.

Soil treatment with urea at a rate supplying 420 pounds of nitrogen per acre gave effective wilt control, and tobacco grown on treated soil in rotation with 1 year of corn produced a normal crop of high-quality leaf. Treatment with chloropicrin also gave effective wilt control, but the cost is too high and the technique of application too inconvenient for large-scale use in the field. Soil treatment with a large number of complex organic chemicals and several modifications of cultural practice did not lessen wilt severity.

Crop rotation, though heretofore only moderately effective, must continue to be used for the control of bacterial wilt. Improved rotation practices are now developed, but even so, this method will not be consistently effective. To obtain the best results, tobacco should be grown after at least 3 years of corn, soybeans, or redtop.

GEOGRAPHIC DISTRIBUTION OF BACTERIAL WILT

Bacterial, or Granville, wilt (*Bacterium solanacearum* E. F. Smith),[2] when first described by Stevens and Sackett in 1903 (*7*),[3] was found only in restricted areas of southern Granville County, N. C. At the present time the disease is uniformly distributed and highly destructive in southern Granville County and in adjoining areas of Wake and Durham Counties. It has been reported also from every county in the State growing flue-cured tobacco, but the most rapid spread during recent years was in several areas of the Coastal Plain. Bacterial wilt has been reported also from Maryland, Virginia, South Carolina,

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[2] *Phytomonas solanacearum* (E. F. Smith) Burgey et al.

[3] Italic numbers in parentheses refer to Literature Cited, p. 15.

Georgia, Florida, and from most of the important tobacco-growing regions of other countries.

NEED OF EFFECTIVE CONTROL

In experiments on wilt conducted in this country from 1903 to 1917 (*3*), it was demonstrated that crop rotation was of value as a control measure. In the Netherlands East Indies, where experimental work was begun about 1890, essentially the same conclusion was drawn (*5*, *9*). These earlier experiments were the basis for the current recommendations of crop rotation and sanitary practices for wilt control, measures that have been extensively used in this country. As practiced by farmers, however, rotation reduced losses from the disease but could not be depended on for adequate control. Even though the best known control measures were used, losses as high as 90 percent have been experienced on some farms. Because the average loss during recent years was 20 percent in the badly infested areas of Granville, Wake, and Durham Counties, N. C., the need was great for more effective rotations or for other practical methods of control.

OUTLINE OF EXPERIMENTAL WORK

In 1935 a broad program of experimental work was instituted on fields near Creedmoor, N. C., in the area where wilt was first reported. The results of host-range studies with *Bacterium solanacearum* (*6*) and of development of resistant breeding stocks (*1*) have already been published. It is the purpose of this circular to report the results of experimental work on crop rotation and chemical treatments of the soil in the control of the disease. The major objective was to increase the effectiveness of crop rotation because of its practicability and of the fact that it was already in general use. It has been assumed that wilt control by rotation depends on the elimination of host plants and hence on starvation of the parasite. On more critical study it was apparent that other factors might play a part in the results obtained and therefore required investigation. The several factors considered were: (1) Effectiveness of rotations of the crop plants commonly grown in the wilt-infested area; (2) effect of recontamination of rotated areas on the degree of control obtained; (3) effect of a small number of susceptible weeds on the control obtained from an otherwise immune growth; (4) seasonal effects on performance of rotations; (5) length of rotation required for effective control; and (6) effect of rotations on the carry-over of infection in soil on different areas of fields.

Less extensive experiments tested rotation in combination with genetic resistance and chemical treatment of the soil. In addition, a group of complex organic compounds were tested as soil treatments. The experiments included many different types of work, and the methods used are presented in different sections of the circular together with the results of the various tests.

CONTROL BY CROP ROTATION

The literature on the control of bacterial wilt repeatedly implies that the absence of susceptible plants during the rotation period assures a high degree of control. This supposition was based on the belief that the parasite would be starved out, thereby eliminating the disease. Following this line of thought, bare fallow rotations could be expected to give complete control. Corn and certain other crops could be expected to give control approaching that of the bare fallow rotations, because they are immune to the disease. Soybean or cowpea rotations could be expected to give moderate control, because they are susceptible under conditions of stem inoculation and hence some carry-over might be anticipated.

The data from carefully conducted experiments failed to support this reasoning. Bare fallow rotations gave some reduction in wilt severity, but they were less effective than rotations with most plants. Soybean, which is susceptible to stem inoculation and was once considered a host plant, was one of the most effective control crops when used in the longer rotations. In addition, there was considerable variability in the control obtained with such immune crops as corn, sorghum, crabgrass, lespedeza, and crotalaria. It is unlikely that these differences can be attributed to susceptible weeds or reinfestation, because careful provision was made to exclude these factors from the rotation experiments, and other tests also showed that reinfestation and the presence of susceptible weeds were of minor importance in determining the degree of control.

It appears, therefore, that two separate factors were operating to give wilt control by crop rotation: (1) The starvation effect associated with an absence of host plants, as illustrated by the slight reduction in extent of wilt obtained with bare fallow rotations; and (2) the crop effect associated with the use of certain plants in the rotation, as illustrated by corn. A comparison of wilt severity on tobacco grown in rotation with bare fallow and with corn showed an average difference in all four trials of 39.4 percent in favor of tobacco grown after corn, proving that the crop effect was considerably more important than the starvation effect. The nature of the crop effect was not investigated, but it is probable that the biological situation in the soil was a factor.

The degree of control obtained from crop rotation was variable. The different experiments provided an opportunity to study several factors thought to be involved. These studies included degree of resistance of the crop plants grown, presence of susceptible weeds in the immune crops, recontamination of the soil during the rotation period, effectiveness of the same rotation in different seasons, length of rotation, and effectiveness of rotations on different areas of the same field. Even though considerable information has been obtained on the control to be expected from rotations, an adequate explanation was not found for the variability observed. Factors of an indirect type, not under positive control, appeared to determine the effectiveness of the rotations.

CROP ROTATION RECOMMENDED

Crop rotation should be recommended until more effective methods are available, even though not found uniformly effective. A rotation period of 3 years or more between tobacco crops is desirable because the longer rotations were more effective during seasons of unusual wilt severity. During seasons when wilt was only moderately severe, however, 1 or 2 years of other crops gave striking reductions in wilt damage. Corn, soybeans, and redtop were the most effective crops tested. Corn tended to give better results than other crops, and hence it is desirable to arrange the cropping system so that corn precedes tobacco.

OTHER CONTROL MEASURES STUDIED

Progress has been made toward the development of more effective control measures. Breeding stocks are on hand that have a high degree of resistance, and much progress has been made in the development of resistant strains of good quality. Excellent results were obtained by treating the soil with urea to control the disease and then growing corn for one season to deplete the soil of excessive nitrogen prior to planting tobacco.

RESULTS WITH CROP ROTATION

Experiment on Small Plots

The major objective of the experiment on small plots was to test several rotations under conditions that provided maximum protection against the spread of the wilt parasite between plots. For this purpose, plots 12 by 24 feet were established on soil demonstrated by tobacco plantings in 1935 to be severely and uniformly infested. Protection was provided from the two chief methods of spread in the following manner: (1) To keep out surface water, side walls were made of pine boards treated with creosote and so constructed that a watertight enclosure extended 8 to 10 inches below and at least 6 inches above the soil surface. (2) To prevent spread of the disease by infested soil, all cultivation was carried out with hand tools and was preceded by sterilization in formaldehyde solution of implements and shoes of workmen. The plots were separated by walkways 4 feet wide, which were kept free of weeds by frequent cultivation, and the entire experimental area was enclosed by a woven-wire fence.

Prevailing cultural practices were followed for the commonly grown crop plants. An almost pure stand of crabgrass (*Digitaria sanguinalis* (L.) Scop.) was obtained from natural seeding by the method of Crafton and Wells (*2*), in which the soil was cultivated about May 1 and left undisturbed the rest of the season. Bare fallow plots were cultivated frequently to keep the soil free of all vegetation. A winter cover crop of rye was grown each year on all plots except those in bare fallow rotations.

Corn, soybeans, and bare fallow were more extensively tested than other rotations because they represented extreme types. Corn provided a rotation of an immune crop. Soybeans provided a rotation of a resistant crop, that is, a plant that was successfully inoculated by artificial means but immune to the disease when grown on badly infested soil in the field (*6*). Bare fallow provided a rotation that was free of crop effects and was expected to give maximum starvation of the parasite. In addition, rotations of crabgrass, lespedeza, cowpeas, *Crotalaria spectabilis*, sorghum, and cotton were tested. Three plots were planted in tobacco each year as controls. Counts of wilted plants made August 1 were closely correlated with yield and were used as a measure of wilt severity. Yield data were not reported for this experiment, because the plots were too small for accurate determinations of quality and value.

The results obtained from the various rotations are given in table 1. Tobacco grown after tobacco was completely destroyed (fig. 1, *A*), all plots showing more than 90 percent infection on August 1 of each year. Bare fallow, the rotation expected to provide the maximum starvation effect, gave measurable control, but less than rotations of most crop plants. A rotation with corn was found to be more effective than with other crops after a cropping period of 1 year, but in longer rotations there was no consistent difference between corn and soybeans (fig. 1, *B* and *C*). Reductions in wilt severity were obtained with all crops tested, but the results were not uniform. For example, tobacco grown after 2 years of corn, crabgrass, and sorghum showed 2, 13, and 71 percent wilted plants, respectively, on August 1, 1938. These three crops are immune to the wilt disease, but were not equally effective in controlling it when used in rotations.

In considering the length of rotation, it was demonstrated in 1939 that a period of 3 years between tobacco crops was more effective than a period of 2 years. Tobacco grown after 3 years of corn or soybeans had 31.5 and 17.5 percent wilted plants, respectively, whereas tobacco grown after a 2-year period (1 year of soybeans and 1 year of corn) had 72.0 percent wilted plants. On comparison between different cropping periods, however, with data obtained during separate seasons, the results were not consistent. For example, tobacco grown in 1937, 1938, 1939, and 1940, following 1, 2, 3, and 4 years of corn, averaged 6.5, 2.0,

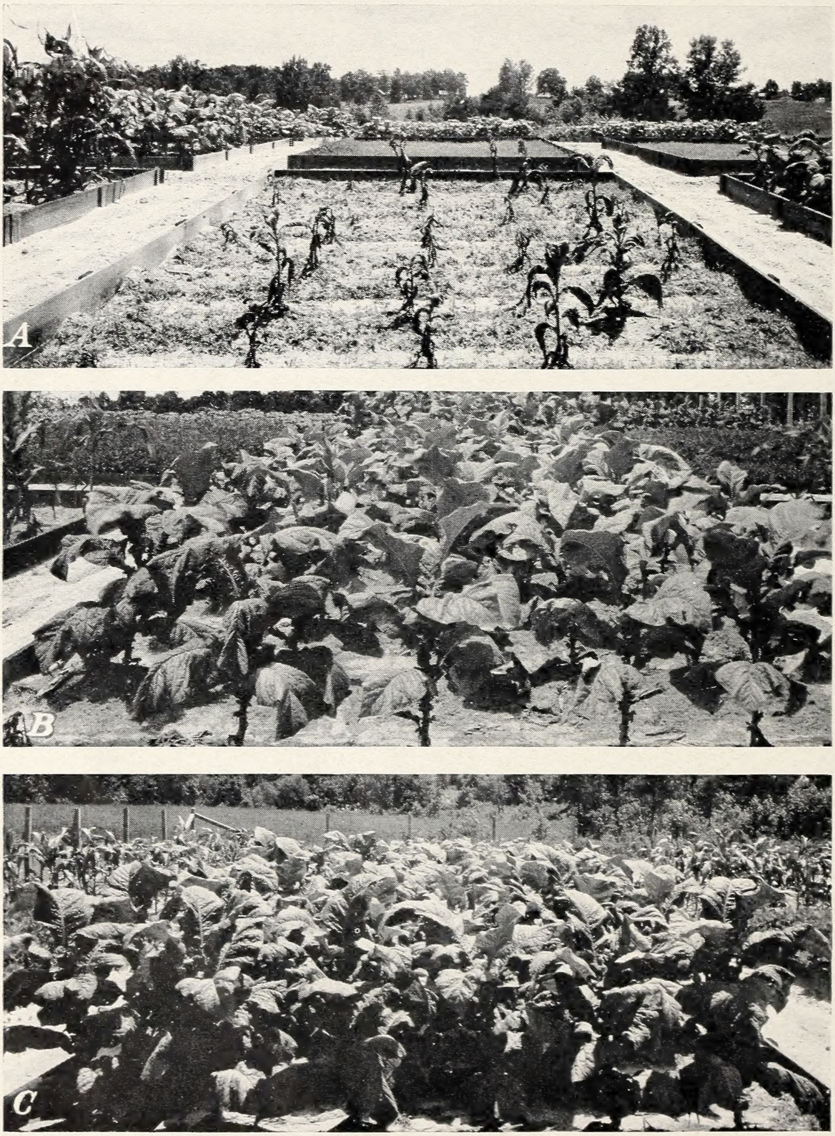

FIGURE 1.—Control of bacterial wilt by crop rotation on small plots: *A*, Tobacco grown after tobacco every year since 1935; *B*, tobacco grown after 3 years of corn; *C*, tobacco grown after 3 years of soybeans. Photographed August 7, 1939.

Table 1.—*Wilt on tobacco grown with crop rotations on small enclosed plots*

Year grown	Preceding crop or fallow	Plants wilted August 1			
		Plot 1	Plot 2	Plot 3	Average
		Percent	*Percent*	*Percent*	*Percent*
1937	Tobacco continuously	[1] 97	91	100	96.0
1938	do	96	98	92	95.3
1939	do	100	100	100	100.0
1940	do	100	94	100	98.0
	1 year of—				
1937	Bare fallow	81	70		75.5
1937	Soybeans	50	38		44.0
1937	Corn	6	7		6.5
1937	Crabgrass	31			
1937	Sorghum	21			
1937	Lespedeza	51			
1937	Cowpeas	62			
1937	*Crotalaria spectabilis*	87			
1940	Cotton	42	48		45.0
	2 years of—				
1938	Bare fallow	43	16		29.5
1938	Soybeans	6	2		4.0
1938	Corn	2	2		2.0
1938	Crabgrass	13			
1938	Sorghum	71			
1938	Lespedeza	10			
1938	Cowpeas	2			
1938	*Crotalaria spectabilis*	19			
1940	Cotton	40			
1938	Soybeans, 1 year, followed by corn, 1 year	12	6		9.0
1939	do	65	79		72.0
1940	do	33	40		36.5
	3 years of—				
1939	Bare fallow	100	37		68.5
1939	Soybeans	10	25		17.5
1939	Corn	38	25		31.5
1939	Crabgrass	50			
	4 years of—				
1940	Bare fallow	44	10		27.0
1940	Soybeans	2	12		7.0
1940	Corn	6	0		3.0
1940	Crabgrass	12			

[1] Approximately 48 tobacco plants per plot.

31.5, and 3.0 percent wilted plants. Another illustration of seasonal variation was obtained on tobacco grown in a rotation of 1 year of soybeans plus 1 year of corn, in which the tobacco had 9.0, 72.0, and 36.5 percent wilted plants in 1938, 1939, and 1940. A period of at least 3 years of other crops appears to be necessary during seasons of exceptional wilt severity, as in 1939, and for this reason the longer rotations are preferable. Periods of 1 or 2 years of other crops, however, gave striking reductions in extent of wilt during seasons of moderate wilt severity, as in 1937 or 1938.

Experiment on Large Plots

The experiment on small plots tested crop rotations under conditions of minimum opportunity for reinfestation by the wilt parasite. In the experiment on large plots crop rotation was tested under field conditions similar to those of practical tobacco culture, where cultivation is carried out by horse-drawn as well as by hand implements. The plots, one-fifth of an acre each, were established on soil shown by a test planting of tobacco in 1935 to be badly and uniformly infested. Flat-bottom drainage ditches 12 or 16 feet wide, seeded to grass, separated the plots on all sides to give protection from reinfestation by surface water. One plot was planted to tobacco each year as a control. Sweetpotato, redtop, crabgrass, corn, and native weeds were compared in rotations, providing 1-, 2-, and 3-year periods between tobacco crops.

The results were similar to those from the small-plot rotation experiment, and the data on tobacco grown in 1937 and 1938, after periods of 1 and 2 years of other crops, are not reported in detail. The data on tobacco grown in 1939, after 3 years of the various crops, however, are of interest because of the exceptional severity of wilt that year. The extent of wilt and the yield and value of the crops are shown in table 2.

Tobacco grown after tobacco was killed by the disease early in the season, and the crop was a complete loss (fig. 2, *A*). The rotation of native weeds gave only slight reduction in wilt severity, but this was expected, as several species of wilt-susceptible weeds were abundant in the fallow. Tobacco grown after 3 years of crabgrass and sweetpotato was also badly diseased. During 1937 and 1938, however, tobacco grown after 1 or 2 years of crabgrass and sweetpotato was not so severely damaged as in 1939, showing that these two rotations varied widely in effectiveness during different seasons. Rotations of redtop and corn (fig. 2, *B*) were the most effective, as shown by the lowest percentages of wilted plants and the highest yields, evaluated by 1939 prices at more than $120 an acre (see table 2, last column). Corn was more effective than other crops in 1937, 1938, and 1939.

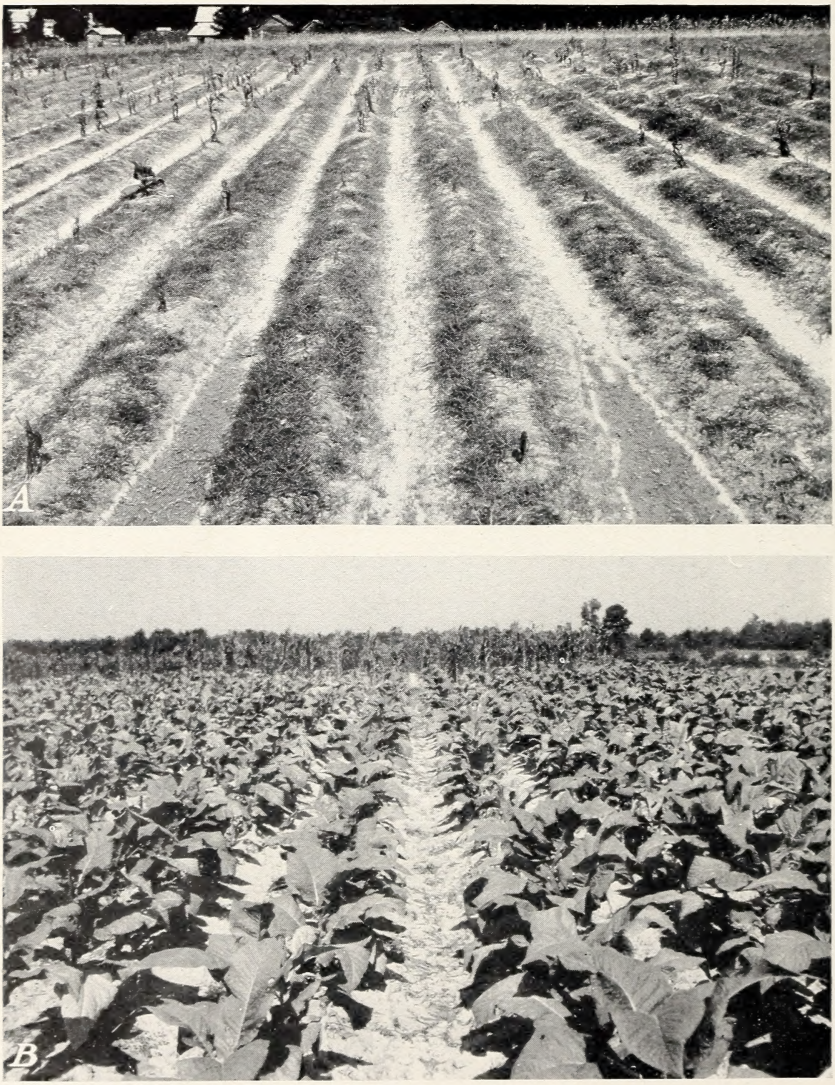

FIGURE 2.—Control of bacterial wilt by rotation on large plots: *A*, Planted in tobacco continuously since 1935; *B*, tobacco growing after 3 years of corn. Photographed July 20, 1939.

TABLE 2.—*Wilt on tobacco grown on large plots in 1939, after 3 years of another crop*

Crop grown for 3 years before tobacco	Tobacco plants wilted August 1	Acre yield of tobacco	
		Weight	Value
	Percent	*Pounds*	*Dollars*
Tobacco	[1] 100	0	0
Native weeds	84	298	48.78
Crabgrass	91	340	55.28
Sweetpotato	75	473	78.09
Redtop [2]	59	733	120.51
Corn	41	809	129.52

[1] Approximately 800 plants per plot.

[2] Sudan grass (*Sorghum vulgare* var. *sudanense* (Piper) Hitchc.) grown in the summer of 1936 and redtop (*Agrostis alba* L.) seeded in the fall of that year.

Wilt increased about 100 percent on all rotated plots later in the season. For example, tobacco grown after the redtop and corn rotations had 59 and 41 percent wilted plants on August 1, 90 and 74 percent by September 1, and by October 1 nearly all the plants were dead on both plots. It was apparent that the increased yields resulted not from elimination of the disease but from a delay in its development until the greater part of the crop was harvested.

EXPERIMENT ON SINGLE-ROW PLOTS

The foregoing experiments were conducted on plots protected from reinfestation. Marked differences were obtained from crop rotation on unprotected plots. In 1936 several varieties of velvetbean were grown in rows 4 feet apart to test their susceptibility to wilt by natural infection, and a row of tobacco was planted in the middle as a control. All the tobacco was killed by wilt, but the velvetbeans remained healthy. In the fall of 1936 and the spring of 1937 the entire area was plowed and harrowed flat. Tobacco was planted and cultivated in the usual way without any effort to prevent the spread of wilt from row to row. The differences were striking in the earlier part of the season, as shown in figure 3, photographed July 21, 1937. By August 15, however, all plants were badly diseased. Similar results were obtained with rotations of crabgrass, cowpeas, and immune weeds during several different seasons, demonstrating that the effects of rotation persist in the presence of maximum opportunity for recontamination.

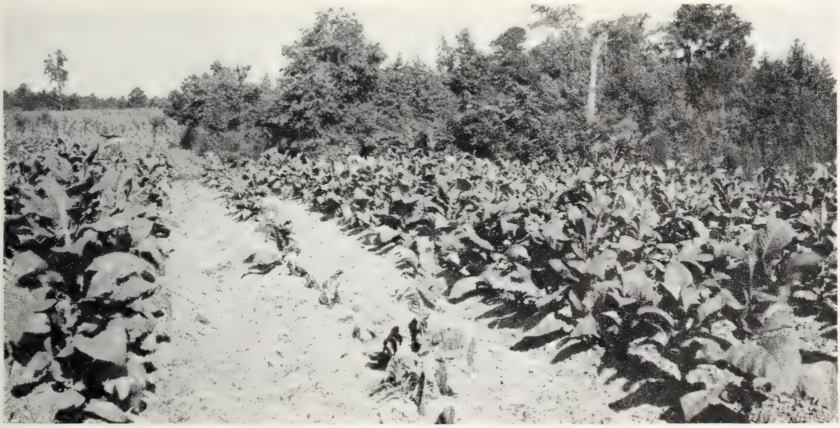

FIGURE 3.—Results with rotation on single-row plots: The middle row was planted in tobacco in 1936; rows on the left and right were planted in velvetbeans in 1936. Photographed July 21, 1937.

RESULTS ON FARMERS' FIELDS

The occurrence of bacterial wilt in spots on many rotated fields suggested that the rotations were not equally effective in all areas of the same field. In order to study this phase of the problem, maps were made of wilt distribution during 1938 and 1940. Permanent plots, each 50 by 50 feet and containing about 260 tobacco plants, were set up, and wilt counts were made about August 1 each year. Data from one field planted in tobacco in 1938, corn in 1939, and tobacco in 1940 are presented in figure 4. The well-defined pattern of wilt distribution was approximately the same in both years. Similar results were obtained on two other fields, one rotated to crabgrass and the other to corn. The entire area of each field had been in rotations of various types for 20 or perhaps 30 years. The rotations, however, had not been uniformly effective. In some areas, as shown in plots 1, 2, 5, 6, 9, and 10 of figure 4, considerable control had been obtained, but in other areas of the same field, as shown in plots 4, 8, and 12, wilt was severe. Therefore the effectiveness of rotations appeared to be dependent on favorable interaction with the soil environment, a condition not under positive control.

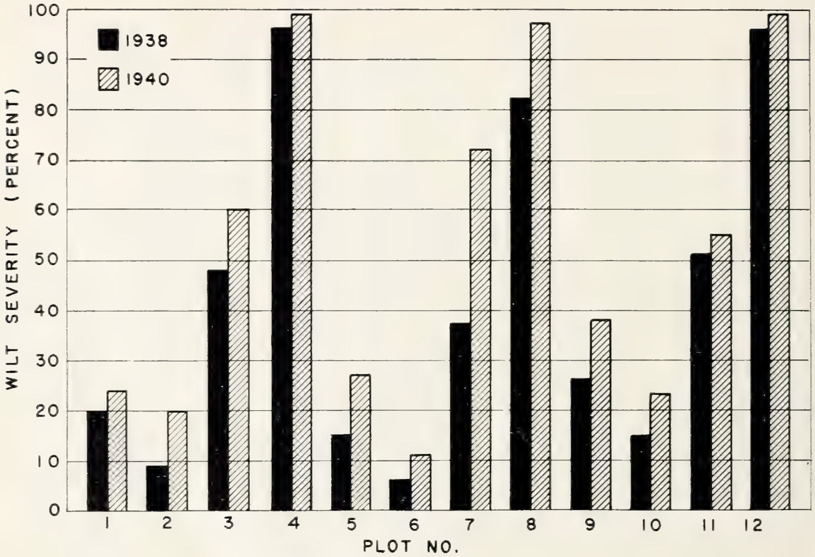

FIGURE 4.—Distribution of wilt in 1938 and 1940 on the same field.

EFFECT OF SUSCEPTIBLE WEEDS

Susceptible weeds growing in the fields and on their borders during the rotation period have been considered by several investigators (*3*, *5*, *9*, and others) a possible cause of the erratic results obtained from crop rotation. A study of this phase of the problem was conducted on six plots in which the wilt control from rotations of weedy corn and weed-free corn was compared.

The weedy corn was grown on three plots as follows: Four plants, one each of ragweed (*Ambrosia artemisiaefolia* L.), horseweed (*Erigeron canadensis* L.), cocklebur (*Xanthium* sp.), and jimsonweed (*Datura stramonium* L.), were transplanted into each 109 linear feet of row and cultivated along with the corn crop. Nearly all the jimsonweed and part of the ragweed were killed by the disease each year. In addition to the weeds transplanted into the corn rows, a border of native weeds 5 feet wide was left on the 2 sides of each plot.

The weed-free corn was grown on three plots by thoroughly roguing the weeds from the plots and borders at frequent intervals.

Comparisons of wilt control were made by planting the rotated plots to tobacco in pairs, one weedy and one weed-free, during four separate seasons. The data are summarized in table 3.

TABLE 3.—*Percentage of wilt on tobacco grown in rotation with weed-free and weedy corn*

Year grown	Preceding years grown	Wilt on tobacco grown after—	
		Weed-free corn	Weedy corn
		Percent	*Percent*
1937	1	[1] 28	21
1938	2	19	30
1939	3	41	46
1940	1	40	17
1940	2	53	48
Average		36.2	32.4

[1] Approximately 800 tobacco plants per plot.

The results show that in some cases tobacco grown after weedy corn had the higher percentage of wilted plants and that in other cases tobacco grown after weed-free corn had the higher percentage. The average wilt percentages for all five comparisons show that susceptible weeds had no effect on the extent of wilt.

Extensive survey work was carried out on farmers' fields to continue this phase of the investigation. During the summer of 1936, the weed floras were carefully studied on 25 infected fields being rotated for wilt control. The weed species were listed, and their respective populations were counted on 50 quadrat samples each of 1 square meter an acre. Of the 103 species observed, the following were known to be susceptible to natural infection (*6*) and hence potential host plants for *Bacterium solanacearum*: Jimsonweed, horsenettle (*Solanum carolinense* L.), croton (*Croton glandulosus* L.), horseweed, black nightshade (*Solanum nigrum* L.), cocklebur (*Xanthium* sp.), ragweed, and *Aster* sp. Nineteen of the surveyed fields were planted to tobacco in 1937, and there was no relation between total weed populations in 1936 and wilt severity in 1937. Ten of the fields had been rotated to corn alone and hence comprised a group within which comparisons could be more closely made. The data in table 4 show the estimated population of susceptible weeds in 1936 and the extent of wilt on tobacco in 1937. The number of susceptible weeds ranged from 0 to 20 individual plants to each 100 square feet in 1936, but showed no consistent relation to the extent of wilt on tobacco in 1937.

TABLE 4.—*Relation of the population of susceptible weeds to severity of bacterial wilt on subsequent tobacco crops*

Number of susceptible weeds per 100 square feet in 1936	Tobacco plants wilted in 1937	Period during which corn preceded tobacco
	Percent	*Years*
0	[1] 27	2
.9	27	3
.2	12	3
.4	36	1
1.7	27	3
1.8	5	1
2.3	35	3
5.3	6	1
16.7	28	1
20.0	28	2

[1] Estimated from counts made on every fifth row about August 1.

In some fields there was a more or less definite pattern of wilt distribution, as shown in figure 4. To determine whether susceptible weeds were associated with this distribution, survey work was conducted on a second group of fields. Counts of weeds known to be susceptible were made in August 1937 on permanently located plots 50 by 50 feet each. In 1938 the fields were planted to tobacco, the plots relocated, and wilt counts made about August 1 on 59 plots in 10 fields. There was no relation between the susceptible weed population in 1937 and the extent of wilted tobacco on plots within the same field in 1938. For all 59 plots the correlation coefficient between the population of known susceptible weeds and the percentage of wilt on tobacco was negative and not statistically significant. Thus, the data from 3 different lines of work showed that weeds known to be susceptible to wilt were not associated with the variations in extent of wilt on tobacco grown the next year.

Genetic Resistance Combined With Rotation

Strains of tobacco now in stock have slight, moderate, and high levels of resistance to wilt (*1*). Strain 448A is especially valuable for breeding, because of its resistance to bacterial wilt and mosaic. Hybrids of this strain crossed on flue-cured varieties have shown a high degree of wilt resistance and considerable resemblance to the flue-cured type. In considering the use of resistant strains in commercial tobacco production, the question arose as to whether a rotation could be combined with genetic resistance to obtain a still higher degree of wilt control. To study this phase of the problem, 24 plots 200 feet long were set up on uniformly infested soil. In 1939 tobacco was grown on half of each plot and corn on the other half. In 1940 six strains of tobacco were tested for resistance in eight randomized blocks, four on soil planted in tobacco in 1939 and four planted in corn in 1939. The relative resistance of the strains used is shown in counts made August 1 (table 5).

Table 5.—*Effect of rotation on degree of wilt in resistant strains of tobacco*

Strain	Wilt on tobacco grown after—		Difference
	Tobacco	Corn	
	Percent	*Percent*	*Percent*
Cash	[1] 93.25	[1] 63.50	[2] 29.75
Davis Special	75.50	48.25	[2] 27.25
T. I. 79A	37.00	23.75	13.25
Xanthi	28.00	22.00	6.00
T. I. 448A	23.25	12.75	[2] 10.50
79X	16.75	8.75	8.00

[1] Mean of 4 replicates; approximately 50 plants per plot.

[2] Significant at the 5-percent level for 3 degrees of freedom.

Cash, one of the standard flue-cured varieties, was the susceptible control. Davis Special was slightly resistant, T. I. 79A and Xanthi were moderately resistant, and T. I. 448A and 79X highly resistant. The differences between rotations within each strain are also shown in table 5. Cash had 29 percent less wilt when grown after corn than when grown after tobacco. The slightly resistant strain Davis Special showed a similar reduction in degree of wilt when grown in the corn rotation. In the other strains, however, the difference between rotations was considerably smaller, showing that little increased control was obtained from the use of moderately or highly resistant strains in combination with the corn rotation.

Urea Treatment Combined With Rotation

In the continuation of studies on soil treatment by the North Carolina station (*4*), Poole and the writer found heavy rates of nitrogenous materials to be of promise. In further tests, 420 pounds of nitrogen an acre applied as urea, ammonium carbonate, or ammonium sulfate gave wilt control when broadcast on the soil surface and mixed into the cultivated layer with spade, moldboard plow, or disk. Urea appeared of more promise for commercial use, and soil treatment with this compound controlled wilt on seven other host plants, including tomato, Irish potato, and eggplant.

Application was more effective in spring than in fall, especially with rates of urea supplying 210 and 105 pounds of nitrogen an acre. Transplants set 6 weeks after treatment in spring were stunted during the early part of the growing season, but following treatment in fall, plant injury of consequence was not experienced.

Tobacco grown in the summer after treatment was worthless commercially because of the excessive nitrogen applied. The leaf did not ripen even though treatment was made the previous fall to promote leaching and the crop fertilized with an 0–10–10 mixture at the rate of 1,000 pounds an acre in an attempt to rebalance the nutrient supply.

Tobacco of good quality was produced on urea-treated soil, however, by growing it in rotation with 1 year of corn in small plot trials completed in 1941 (fig. 5). This experiment was repeated in 1943 at five locations, in which the tobacco ripened and cured well. At one location where data were taken on plots in triplicate, the 1,000-pound rate of urea averaged 977 pounds of tobacco an acre that sold for $39.30 a hundredweight, a normal yield and value for the sandy loam soil on which the test was conducted.

The quantity of urea required for wilt control, when used in combination with the corn rotation, was investigated on a total of nine replicates at the five loca-

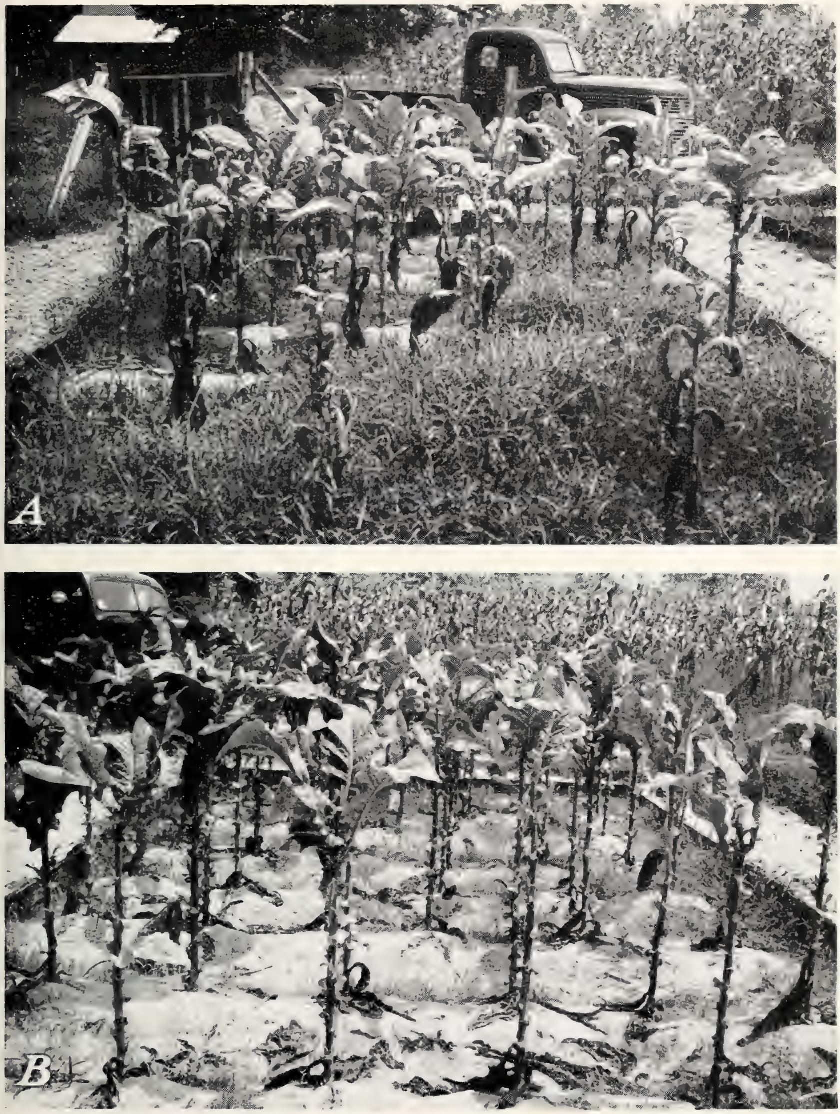

Figure 5.—Control of wilt by a combination of rotation and urea treatment of the soil. *A*, Tobacco grown after 1 year of corn, badly wilted. *B*, Tobacco grown on soil treated with urea prior to planting corn, showing much less wilt; the leaves ripened and cured well.

tions previously mentioned. These sites were selected during the summer of 1941 in fields where 90 to 100 percent of the tobacco was killed by wilt. Rates of 250, 500, and 1,000 pounds of urea (commercial grade containing 42 percent nitrogen) were applied in October 1941 or March 1942, corn was grown in 1942, and tobacco in 1943.

Corn made vigorous growth in all places. At one site where 500 pounds of 0–10–10 fertilizer an acre was applied under the crop on plots in triplicate treatments of 250, 500, and 1,000 pounds of urea, corn averaged 27.1, 46.8, and 55.8 bushels an acre, respectively.

The extent of wilt on tobacco grown in 1943 is summarized in table 6. As shown, the 250- and 500-pound rates gave wide variations in wilt, and on most plots reductions in wilt severity were not adequate. The 1,000-pound rate gave greater and more uniform reductions in disease severity, in that 20 percent was the maximum of wilt on any plot where this treatment was used. An average of 13 percent wilt occurred on all nine replicates, a reduction considered satisfactory for commercial use.

Rate in pounds per acre	Block No.									Mean
	1	2	3	4	5	6	7	8	9	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
250	[1] 42	59	73	65	81	45	59	53	90	[2] 63.0
500	20	31	48	35	27	19	46	45	57	36.4
1,000	10	10	17	17	7	11	20	17	8	13.0

[1] Counts made Aug. 1 on plots of 70 to 110 plants each.
[2] Least significant difference at 1 percent level: 18.47.

The cost of 1,000 pounds of commercial-grade urea needed to treat 1 acre was $40, based on pre-war prices. Hence, soil treatment with this material appears economically sound in view of the increased corn yields obtained and the prevention of loss from wilt. This loss often exceeds $100 an acre.

Soil type is known to affect results obtained with the urea treatment. The experiments reported here, which have been uniformly satisfactory, were conducted on sandy soils low in organic matter. Evidence has accumulated that tends to show this treatment to be of less value on the heavier soil types or on soils with a high content of organic matter.

TABLE 6.—*Percentage of wilt on tobacco grown in rotation with 1 year of corn on soil treated with commercial urea (42 percent nitrogen)*

CHEMICAL TREATMENTS OF THE SOIL

TESTS WITH CHLOROPICRIN

Chloropicrin was tested during the three seasons 1939 to 1941. The data reported in table 7 show the results of a test in which this chemical was injected to a depth of 7 inches in October 1939, the soil covered immediately with glue-coated paper, and tobacco planted in May 1940. In these and other trials good control but not eradication of the disease has been consistently obtained where glue-coated paper was used or where the upper inch or two of soil was wetted to confine the chemical. Less effective control was obtained when applications were made about 1 month before transplanting by injecting 1 cc. of chloropicrin at intervals of 1 foot on each side of the prepared list without paper or water seals. Further experiments failed to develop more practical methods of application. It was concluded that the chloropicrin treatment could be used to good advantage on plant beds, gardens, or other small areas. Its cost was too high, however, and the technique of treatment too inconvenient for use in large-scale field operations.

Table 7.—*Control of wilt by chloropicrin treatment of the soil*

Rate per square foot (cubic centimeters)	Plot	Tobacco plants wilted on—				
		July 1	July 15	Aug. 1	Aug. 15	Sept. 1
		Percent	*Percent*	*Percent*	*Percent*	*Percent*
0	1	[1] 58	98	100	100	100
	2	73	92	94	100	100
1	1	0	2	10	21	77
	2	0	0	10	10	75
2	1	0	0	0	4	46
	2	0	0	0	4	30
4	1	0	0	0	2	31
	2	0	0	4	7	22
8	1	0	0	4	4	19

[1] Approximately 48 plants per plot.

Tests With Complex Organic Compounds

The results obtained on several plant and animal pathogens with biologically synthesized materials (*8*) suggested that some of the more complex organic compounds might be of value as soil treatments. Fifty-three compounds, some of which are synthesized by micro-organisms in culture, were tested in the greenhouse or in the field as soil treatments at rates of 12.5, 25, or 50 pounds an acre. Some of the compounds were highly toxic for tobacco at the lower rate, but none of them reduced wilt severity.

MODIFICATIONS OF CULTURAL PRACTICES

Several modifications of the usual cultural practices were made, to observe their effect on wilt development. Tobacco was transplanted through mulch paper and grown without further root injury from cultivation. Many plants remained apparently healthy until midsummer, but all were finally killed by the wilt disease. In a date-of-planting experiment, tobacco was set April 26 and May 25, 1939. The disease developed first on the early planting, but both plantings were uniformly and badly diseased on July 1. Tobacco and corn were grown in alternate hills, spaced 12 and 30 inches apart in the same row, but all tobacco was killed by the disease. Many farmers believe that opening the tobacco rows with two furrows of a large moldboard plow after harvesting is completed helps control wilt. This is a good practice for several reasons, but it did not modify wilt severity. In another test the soil was turned with spades to depths of 5, 7, 9, and 13 inches. The tobacco plants on all plots were killed by the disease, which developed most rapidly on the plot spaded 13 inches deep. It was concluded that such variations in cultural methods do not lessen the severity of the disease.

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